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COMPARISON OF POWER SYSTEM STABILIZER DESIGN BASED ON LOCAL AND GLOBAL MODEL

C. Lv*, W. Du[†], T. Littler*

*Queen's University Belfast, UK

clv01@qub.ac.uk; t.littler@ee.qub.ac.uk

[†]North China Electric Power University, Beijing, China

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Abstract

This paper introduces a localized phase compensation method for the design of power system stabilizers (PSSs) to suppress the oscillation occurred in a single-machine infinite-bus (SMIB) power system. The proposed method is used to design stabilizers to suppress power system oscillations and only requires the available generator and transformer parameters thus eliminating the need to receive and verify entire power system parameters. This paper establishes the extended linear Phillips-Heffron model for a SMIB system with a PSS installed in the generator and demonstrates application of the model to determine damping and thus preserve power system oscillation stability. The paper also presents several examples where the proposed method has been used with two models to design PSSs with comparative results presented in a case study.

1 Introduction

Power system low-frequency oscillations threaten the security of power system operation as in some cases they may interrupt stable operation of systems. One effective way of suppressing the oscillations is that the auxiliary controllers which formed power system stabilizers (PSSs) are installed in the excitation power system of generators, to provide additional damping to the low-frequency power oscillations [1-2]. Since 1970s a variety of design procedures and algorithms have been proposed for the design of power system stabilizers using either linear or nonlinear models of power system.

On the basis of the damping torque principle, Gibbard [3-5] and Wang [6-7] have investigated the stabilizer design based on global model of power system. For a long time period, damping torque principle has been considered as an engineering heuristics [8]. However, it needs the parameters of the whole network and the generators to apply the method of modal analysis. Thus the extension of the phase compensation method becomes very complicated and the simplicity of the global model is lost. That is the reason why that the modal analysis has been more often used for the design of stabilizers to suppress the inter-area power oscillation in systems.

Recently Gurralla and Sen suggested one approach which employs the secondary bus voltage of generator's step-up transformer to establish a Phillips-Heffron model and applying the phase compensation method to design [9]. The application not only keeps the advantage of simplicity of the global phase compensation method, but also does not require the information of complete power system, which in practice may not always be readily available and is difficult to be validated when the system scale is large and complex [10-11].

This paper introduces a localized phase compensation method for the design of power system stabilizers (PSSs) to suppress the oscillation occurred in a single-machine infinite-bus (SMIB) power system. The proposed method is used to design stabilizers to suppress power system oscillations and only requires the available generator and transformer parameters thus eliminating the need to receive and verify entire power system parameters. This paper establishes the extended linear Phillips-Heffron model for a SMIB power system with a PSS installed in the generator and demonstrates applications of the model on aspects of damping determination and thus power system oscillation stability preservation. This paper also presents several examples where the proposed method has been used with two models to design PSSs with comparative results presented in a case study.

2 Local and global model of power system

2.1 Local model

Fig.1 shows a single-machine infinite-bus power system with one transformer.

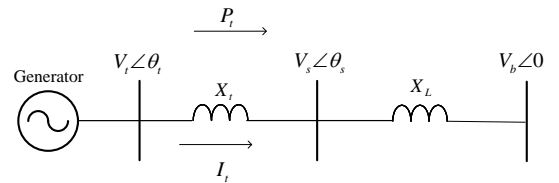


Figure 1: Single-machine infinite-bus power system

The system shown in figure 1 is used to obtain the linearized dynamic model (extended Phillip-Heffron model). The dynamic equations of the power system are as follows:

$$\begin{aligned}
\dot{\delta} &= \omega_0 (\omega - 1) \\
\dot{\omega} &= \frac{1}{M} [P_M - P_t - D(\omega - 1)] \\
\dot{E}'_q &= \frac{1}{T_{d0}} (-E'_q + E_{fd}) \\
\dot{E}'_{fd} &= -\frac{1}{T_A} E'_{fd} + \frac{K_A}{T_A} (V_{ref} - V_t + u_{pss})
\end{aligned} \quad (1)$$

Where

$$\begin{aligned}
P_t &= E'_q i_q + (X_q - X'_d) i_d i_q \\
E_q &= E'_q + (X_d - X'_d) i_d \\
E_{fd} &= E_{fd0} + E'_{fd} \\
V_{td} &= X_q i_q \\
V_q &= E'_q - X'_d i_d
\end{aligned} \quad (2)$$

Fig.2 shows the local Phillips-Heffron model of single-machine infinite-bus power system.

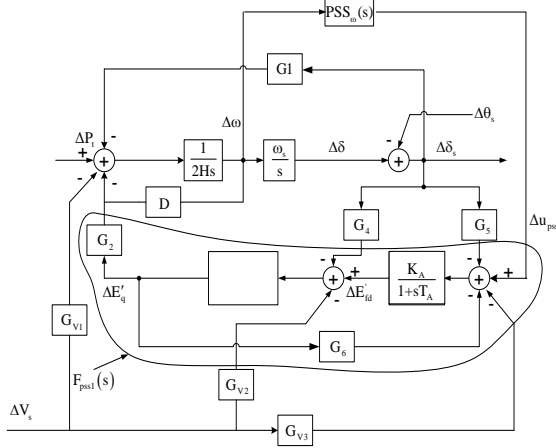


Figure 2: Local Phillips-Heffron model of SMIB power system

The reference axis of local model is V_s in power system, with the reactance of transmission line X_L ignored.

Linearization of Eq.(1), it can be obtained that:

$$\begin{aligned}
\Delta \dot{\delta} &= \omega_0 \Delta \omega \\
\Delta \dot{\omega} &= \frac{1}{M} (-G_1 \Delta \delta_s - G_2 \Delta E'_q - G_{V1} \Delta V_s - D \Delta \omega) \\
\Delta \dot{E}'_q &= \frac{1}{T_{d0}} (-G_3 \Delta E'_q - G_4 \Delta \delta_s - G_{V2} \Delta V_s + \Delta E_{fd}) \\
\Delta \dot{E}'_{fd} &= -\frac{1}{T_A} \Delta E'_{fd} + \frac{K_A}{T_A} (-G_5 \Delta \delta_s - G_6 \Delta E'_q - G_{V3} \Delta V_s + \Delta u_{pss})
\end{aligned} \quad (3)$$

The parameters of PSS can be set to satisfy with phase compensation method for the PSS to provide a pure positive damping torque. The forward path of the output signal of PSS is given as follow:

$$F_{pss1}(s) = \frac{G_2 K_A}{(G_3 + j\omega_s T_{d0})(1 + j\omega_s T_A) + G_6 K_A} \quad (4)$$

Where

$$\begin{aligned}
G_2 &= i_{q0} \left(1 - \frac{X'_d - X_q}{X'_d + X_t} \right) = \frac{X_q + X_t}{X'_d + X_t} i_{q0} \\
G_3 &= \frac{X_d + X_t}{X'_d + X_t} \\
G_6 &= \frac{V_{tq0} X_t}{V_{t0} (X'_d + X_t)}
\end{aligned}$$

The damping torque contributed by PSS to the electromechanical oscillation loop is D_{pss1} . Then the parameters of PSS are set by phase compensation method:

$$\begin{aligned}
K_{pss1} \frac{(1 + j\omega_s T_2)}{(1 + j\omega_s T_1)} &= \frac{D_{pss1}}{F_{pss1}} \angle -\frac{\phi}{2} \\
K_{pss2} \frac{(1 + j\omega_s T_4)}{(1 + j\omega_s T_3)} &= 1.0 \angle -\frac{\phi}{2}
\end{aligned} \quad (5)$$

And the dynamic equations are shown below:

$$\begin{aligned}
\Delta y &= K_{pss2} \frac{1 + sT_4}{1 + sT_3} \Delta \omega \\
\Delta u_{pss} &= K_{pss1} \frac{1 + sT_2}{1 + sT_1} \Delta y
\end{aligned} \quad (6)$$

From computational results above, the state equation of the power system with full mathematical model of the generator applied can be established as follow:

$$\dot{\mathbf{X}} = \mathbf{A}_g \mathbf{X} \quad (7)$$

\mathbf{A}_g is the closed-loop matrix of power system installed with PSS.

Thus, the local oscillation mode is moved to $\lambda_g = \zeta_g + j\omega_g$ based on the local model of power system installed with a PSS.

2.2 Global model

The reference axis of global model is V_b , and the reactance of transformer and transmission line is $X_L + X_t$. Hence the linearization of simplified global model in power system is:

$$\begin{aligned}
\Delta \dot{\delta} &= \omega_0 \Delta \omega \\
\Delta \dot{\omega} &= \frac{1}{M} (-K_1 \Delta \delta - K_2 \Delta E'_q - D \Delta \omega) \\
\Delta \dot{E}'_q &= \frac{1}{T_{d0}} (-K_3 \Delta E'_q - K_4 \Delta \delta + \Delta E_{fd}) \\
\Delta \dot{E}'_{fd} &= -\frac{1}{T_A} \Delta E'_{fd} - \frac{K_A}{T_A} (K_5 \Delta \delta + K_6 \Delta E'_q - \Delta u_{pss})
\end{aligned} \quad (8)$$

Fig.3 shows the global Phillips-Heffron model of single-machine infinite-bus power system.

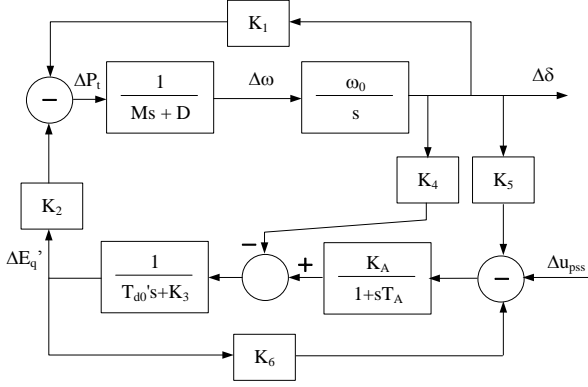


Figure 3: Global Phillips-Heffron model of SMIB power system

The power system stabilizer (PSS) can be designed by using the method of phase compensation and installed to provide a pure damping torque D_{pss2} . The expression for the forward path is given by:

$$F_{pss2}(s) = \frac{K_2 K_A}{(K_3 + j\omega_s T_{d0}')(1 + j\omega_s T_A) + K_6 K_A} \quad (9)$$

Where

$$K_2 = \frac{V_b}{X_d' + X_t + X_L} \sin \delta_0$$

$$K_3 = \frac{X_d' + X_t + X_L}{X_d' + X_t + X_L}$$

$$K_6 = \frac{V_{tq0}}{V_{t0}} \frac{X_t + X_L}{X_d' + X_t + X_L}$$

The PSS design based on global model is the same as it is in Eq.(5). From computational results above, the state equation of the power system with full mathematical model of the generator applied can be established as follow:

$$\dot{\mathbf{X}} = \mathbf{A}_k \mathbf{X} \quad (10)$$

\mathbf{A}_k is the closed-loop matrix of power system installed with a PSS.

Thus, the global oscillation mode is moved to $\lambda_k = \xi_k + j\omega_k$ based on the global model of power system installed with a PSS.

3 Case Study

3.1 The comparison between local and global model with different load conditions

From Eq.(4) and Eq.(9), the transfer function of the forward path of the stabilizer at the oscillation frequency is calculated as follows:

$$F_{pss1} = 0.1995 - j0.5166 = 0.5524 \angle -69.2744^\circ$$

$$G_2 = 0.8094 \quad G_3 = 2.5000 \quad G_6 = 0.4673$$

$$F_{pss2} = 0.1781 - j0.3998 = 0.4376 \angle -65.9867^\circ$$

$$K_2 = 0.6871 \quad K_3 = 2.0000 \quad K_6 = 0.6199$$

And from Eq.(7) and Eq.(10), the oscillation modes of single-machine infinite-bus power system are shown in tables below:

| | Oscillation mode |
|------------------------|-----------------------|
| Without the stabilizer | $-0.0821 \pm j5.4072$ |
| With the stabilizer | $-0.6911 \pm j5.2783$ |

Table 1: Local Oscillation mode of power system

| | Oscillation mode |
|------------------------|-----------------------|
| Without the stabilizer | $-0.0896 \pm j5.6643$ |
| With the stabilizer | $-0.7478 \pm j5.5886$ |

Table 2: Global Oscillation mode of power system

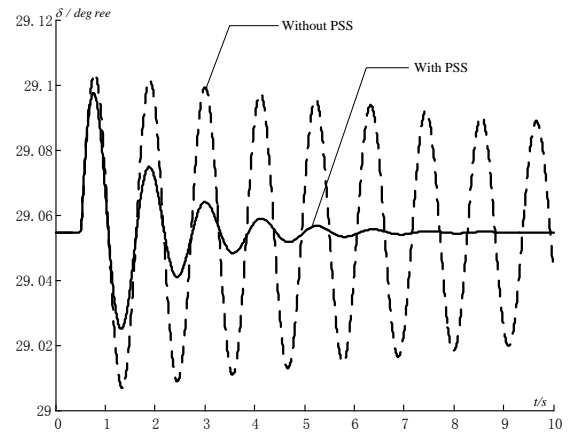


Figure 4: Simulation results of oscillation modes based on local model with or without a PSS installed

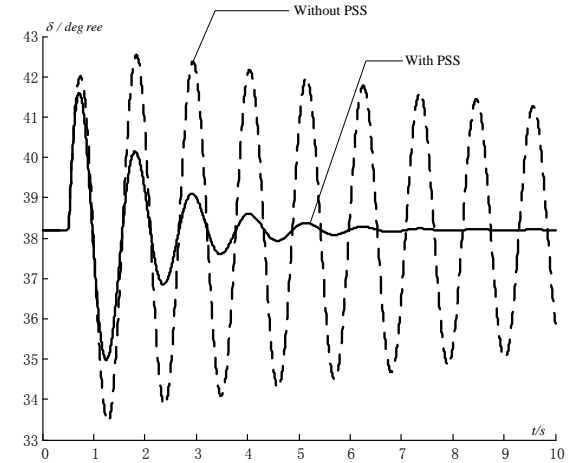


Figure 5: Simulation results of oscillation modes based on global model with or without a PSS installed

To validate the effectiveness of the stabilizer, table 1 gives the computational results of the local oscillation mode of the power system and table 2 gives the computational results of the global oscillation mode of the power system. Figure 4 and figure 5 show the non-linear simulation results of local and global of the power system respectively.

Then the load condition is changed from 0.2 to 0.8 per unit in power system. Table 3 and table 4 give the local oscillation modes and global oscillation modes in power system under different load conditions.

| Load condition (per unit) P_{t0} | Oscillation mode $\bar{\lambda}_g$ |
|---------------------------------------|------------------------------------|
| 0.2 | $-0.3280 \pm j5.2983$ |
| 0.5 | $-0.6911 \pm j5.2783$ |
| 0.8 | $-0.8657 \pm j5.2467$ |

Table 3: Local oscillation mode with different load condition

| Load condition (per unit) P_{t0} | Oscillation mode $\bar{\lambda}_k$ |
|---------------------------------------|------------------------------------|
| 0.2 | $-0.3535 \pm j5.3314$ |
| 0.5 | $-0.7476 \pm j5.5888$ |
| 0.8 | $-0.9161 \pm j5.7171$ |

Table 4: Global oscillation mode with different load condition

Above of all, it can be seen that two stabilizers are designed successfully by using the phase compensation method. The power oscillation is effectively suppressed by the stabilizer installed in the generator. The stabilizer designed based on local model of power system retain the robustness of the one designed based on global model in terms of damping oscillations.

3.2 Influence of transmission line with local and global model

The reactance of transmission line is changed from 0.3 to 0.6 per unit and the other parameters of power system remain unchanged. From Eq.(4) and Eq.(9), the transfer functions of the forward path of the stabilizers at the oscillation frequency are calculated to be:

$$F_{pss1} = 0.2672 - j0.5740 = 0.6331 \angle -65.0376^\circ$$

$$G_2 = 0.8094 \quad G_3 = 2.5000 \quad G_6 = 0.4673$$

$$F_{pss2} = 0.2074 - j0.3624 = 0.4176 \angle -60.2158^\circ$$

$$K_2 = 0.6076 \quad K_3 = 1.7500 \quad K_6 = 0.6981$$

Fig.6 and fig.7 show the simulation results of local model and global model respectively. Compared with the previous power system ($X_L = 0.3$), the values of parameters in global model (K_2, K_3, K_6) are changed, and the values of parameters in

local model (G_2, G_3, G_6) are invariable. It is found that the global model is influenced by transmission line reactance so that the design of PSS is inaccurate. Thus, the local oscillation mode is $\lambda_g = -0.5750 \pm j4.4237$ and the global oscillation mode is $\lambda_k = -0.5677 \pm j4.8813$.

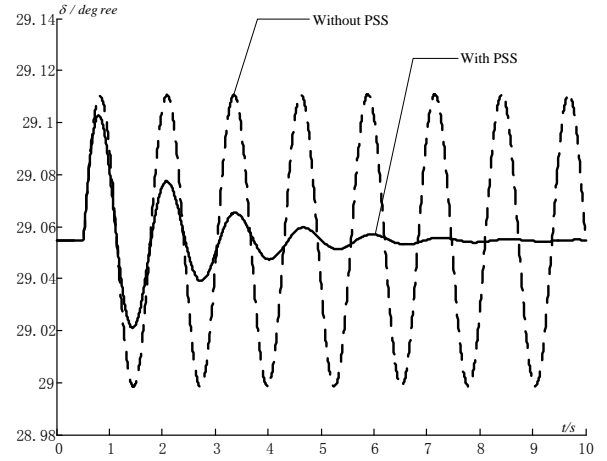


Figure 6: Simulation results without/with PSS in local model when $X_L = 0.6$

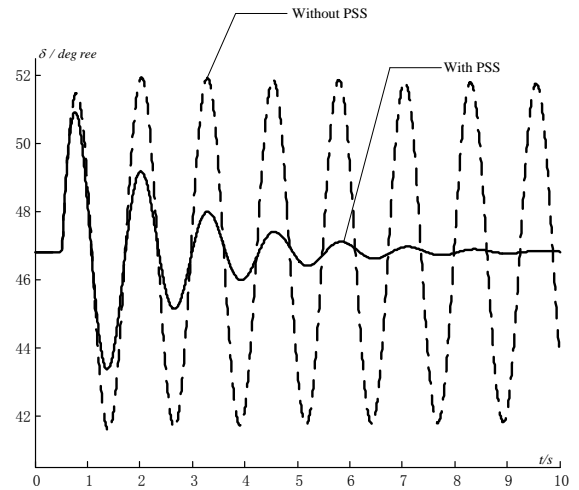


Figure 7: Simulation results without/with PSS in global model when $X_L = 0.6$

From fig.6 and fig.7, it can be obtained that: the local model can ignore the influence of transmission line reactance on power system, which is the advantage of local model for design power system stabilizer by using localized compensation method in SMIB power system to damp oscillations. Actually, it is difficult to measure the reactance of transmission line in the practical engineering so that the designing of PSS based on local model is better than the global model in power system.

4 Conclusion

Power system stabilizer is always a local power device, and most of design methods must rely on a mathematical model of

the whole power system which is known as global model. This paper proposes a localized phase compensation method, which only requires the locally available information of the generator and the transformer. Thus it avoids the difficulty to obtain and validate the complete power system information for design of the stabilizers. The simulation result of designing a stabilizer attached on the generator in a single machine infinite-bus power system by using the proposed method is given in the case study. Comparison between the results obtained by local and global model validates the success of localized phase compensation method to design the stabilizers and can be used to effectively suppress power oscillations. The robustness of localized phase compensation method based on the local model is the same as conventional phase compensation method based on the global model in terms of design of power system stabilizer in power system. It is found that the local model can ignore the influence of transmission line reactance in power system, which is the advantage of local model for design power system stabilizer by localized compensation method in SMIB power system. As it is difficult to measure the reactance of transmission line in the practical engineering, the PSS design based on local model is better than the global model in power system.

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Appendix

Parameters of example single-machine infinite-bus power system (in per unit except indicated):

Generator

$$X_d = 1.18, X_q = 1.0, X_{ad} = 1.0, X_f = 1.13, X_d' = X_d - \frac{X_{ad}^2}{X_f} = 0.2951,$$

$$M = 7, D = 0, T_{d0}' = 5.044s$$

Transmission line

$$X_L = 0.3, X_t = 0.3$$

AVR

$$T_A = 0.01, K_A = 20.0$$